Improving the Fuel Efficiency of New & Existing Vessels

Design & Operational Measures

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Agenda

- Introduction
- Fuel efficiency considerations
  - Vessel type, trade, operational profile
- Improving operational performance
  - Technical design features
    - Newbuilds and existing vessels
  - Operational measures
- Summary

Energy Efficiency: Key Issues

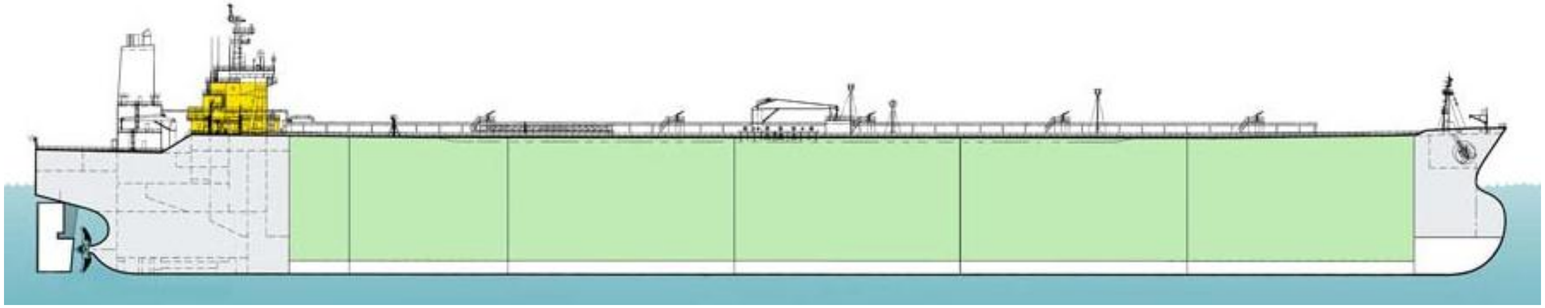
- High fuel cost
  - Increased from $140 to $600 per ton
- Global economy (volatile freight rates)
- Overcapacity of new tonnage
- Regulatory landscape
  - Ballast water treatment
  - ECA
  - EEDI, EEOI, SEEMP, MRV
- Many energy-saving technologies
- Eco ships
- Many stakeholders
- Financing

Fuel Efficient Vessel Operation

- Newbuilding
  - Energy efficient ships, yard spec., contract details
  - Design for operational profile, hull and machinery
  - Optimization, cost effective solutions
- Retrofit on existing fleet
  - Propulsion optimization, bow, propeller/ME etc.
  - Energy-saving devices
  - Machinery optimization for new operational profile
  - Increase cargo capacity
- Operational vessel performance
  - Technical
  - Operational optimization
- Environmental compliance
  - SEEMP, EEDI, MRV
  - SOx, NOx, ECA areas
  - Ballast water treatment

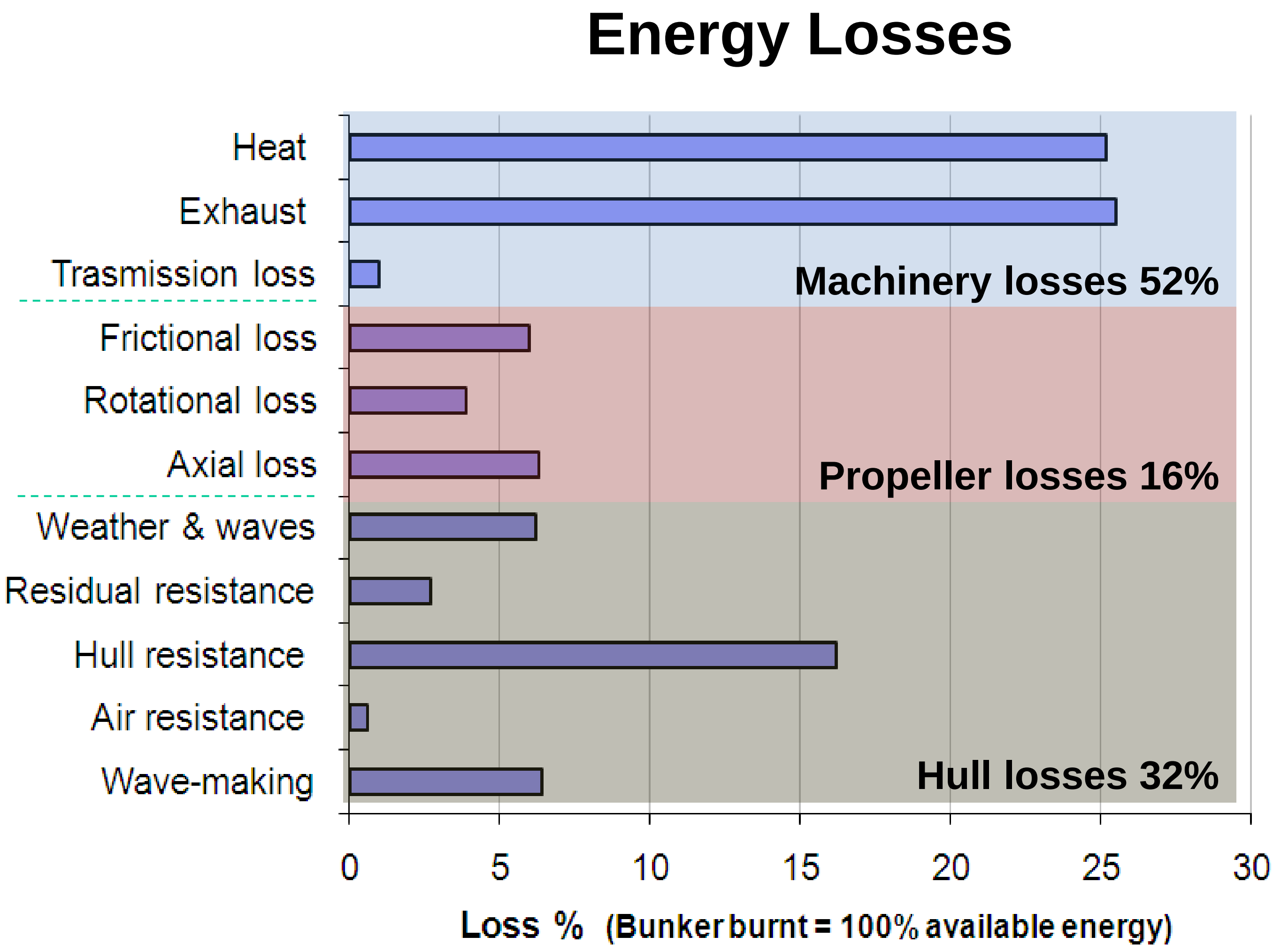
Energy Loss in Propulsion: Full Block Ship

- Propulsion – top three energy losses:
  - Engine heat loss ~50%, hull resistance ~30%, propeller loss ~14%



	Large tanker or bulk carrier (K. Ouchi, ISSDC, 2009)				
	Diesel engine (heat/rotation)	Shaft (transmission efficiency)	Propeller (rotation/thrust)	Sea Margin (real sea effect)	Hull
Efficiency	0.5	0.98	0.72	0.85	
Causes	Heat of exhaust gas & cooling water	Friction of bearing and seal	Momentum, viscosity and rotational flow	Wind, waves. And ship motion	Friction, pressure, wave making
Energy loss	50%	1%	14%	5%	30%

Mitigation of Energy Losses



Reduction of Energy Losses

- Waste heat recovery systems
- Improve engine thermal efficiency

- Propeller, energy-saving devices: PBCF; Mewis duct; contra-rotating propellers; etc.

- Hull form optimization
- Reduce skin friction resistance: LSE coating; air lubrication
- Refine bow and stern

Source: IMO 2nd GHG Study: distribution of energy losses for a tanker in BF6

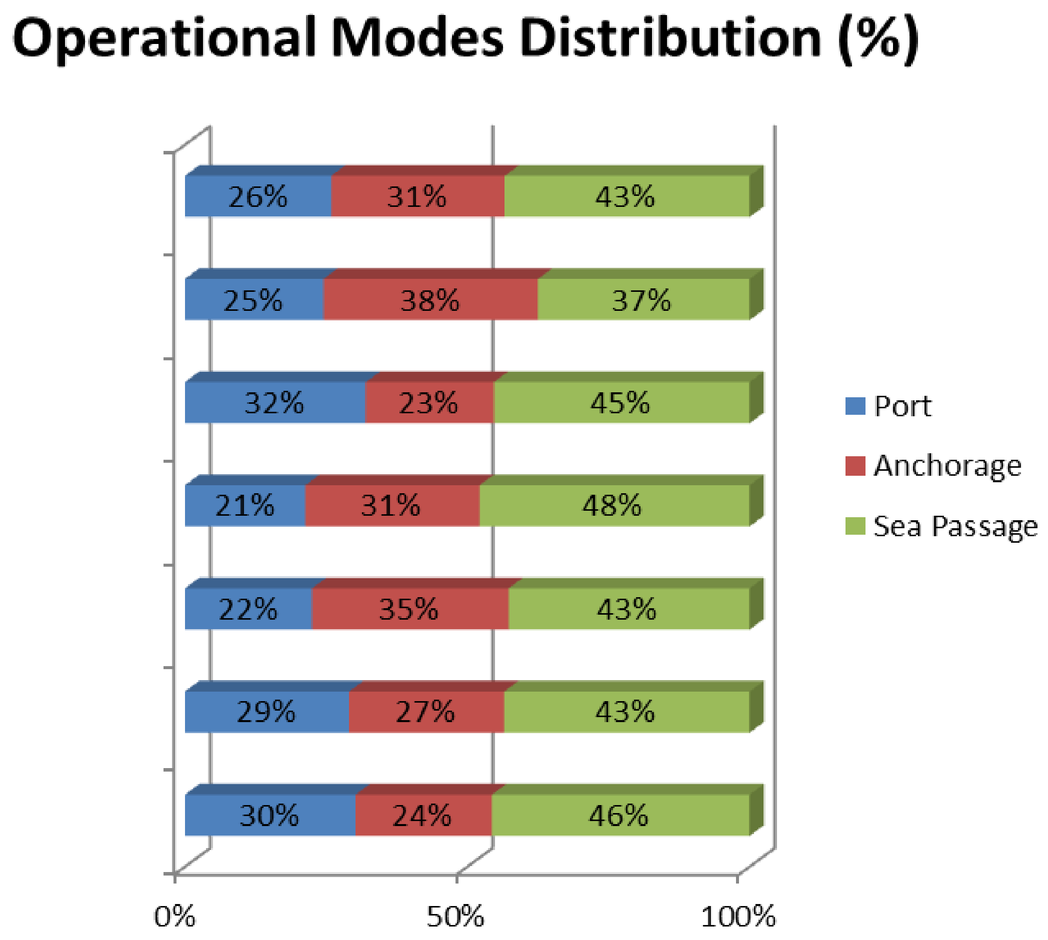
Example of Shipping: Tanker Types & Trades

- Simple product
  - < 10 different cargoes (mainly oil and fuel)
- Advanced product
  - < 20 cargoes (as above + chemicals, caustic soda)
- Parcel
  - 100s of cargoes
- Size and trade:
  - < 10k DWT — Short sea, 75 cargoes/tank/year
  - 10k – 20k DWT — More local trade, 10 cargoes/tank/year
  - > 20k DWT — Deep sea trade, 4 cargoes/tank/year

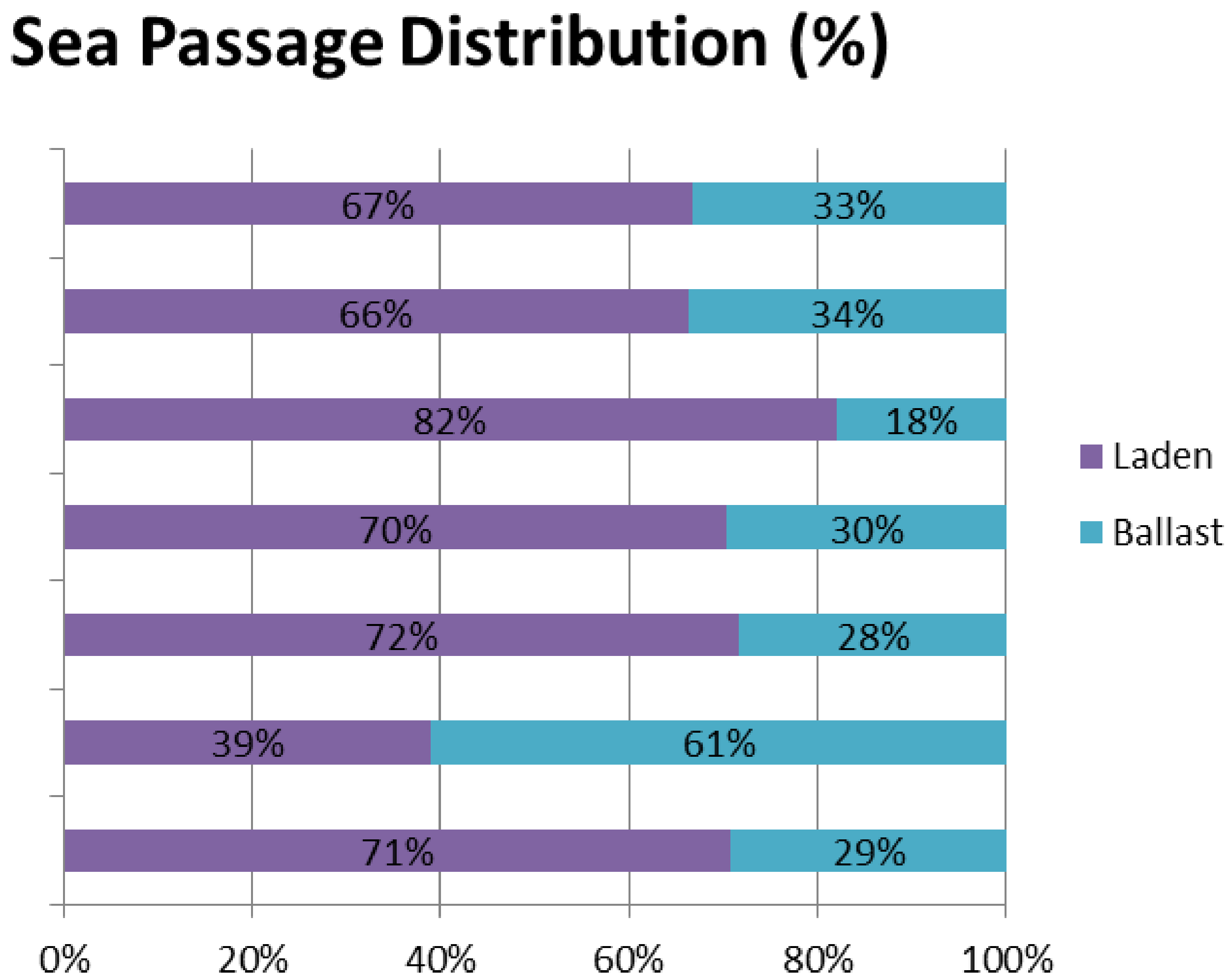
Energy Consumption as a Function of Operational Mode: Tankers

- Propulsion
  - 70 – 90% (highest % for simple product tankers)
- Cargo temperature control
  - 0 – 10% (lowest % for simple product tankers, highest for parcel tankers)
- Tank cleaning
  - 5 – 15% (highest % for parcel tankers, lower for product tankers)
- Loading and discharging
  - < 5% (high % for smaller tankers, lower for the larger vessels)
- Hotel load
  - Approximatley 5%

Operational Profile: Examples for Tankers

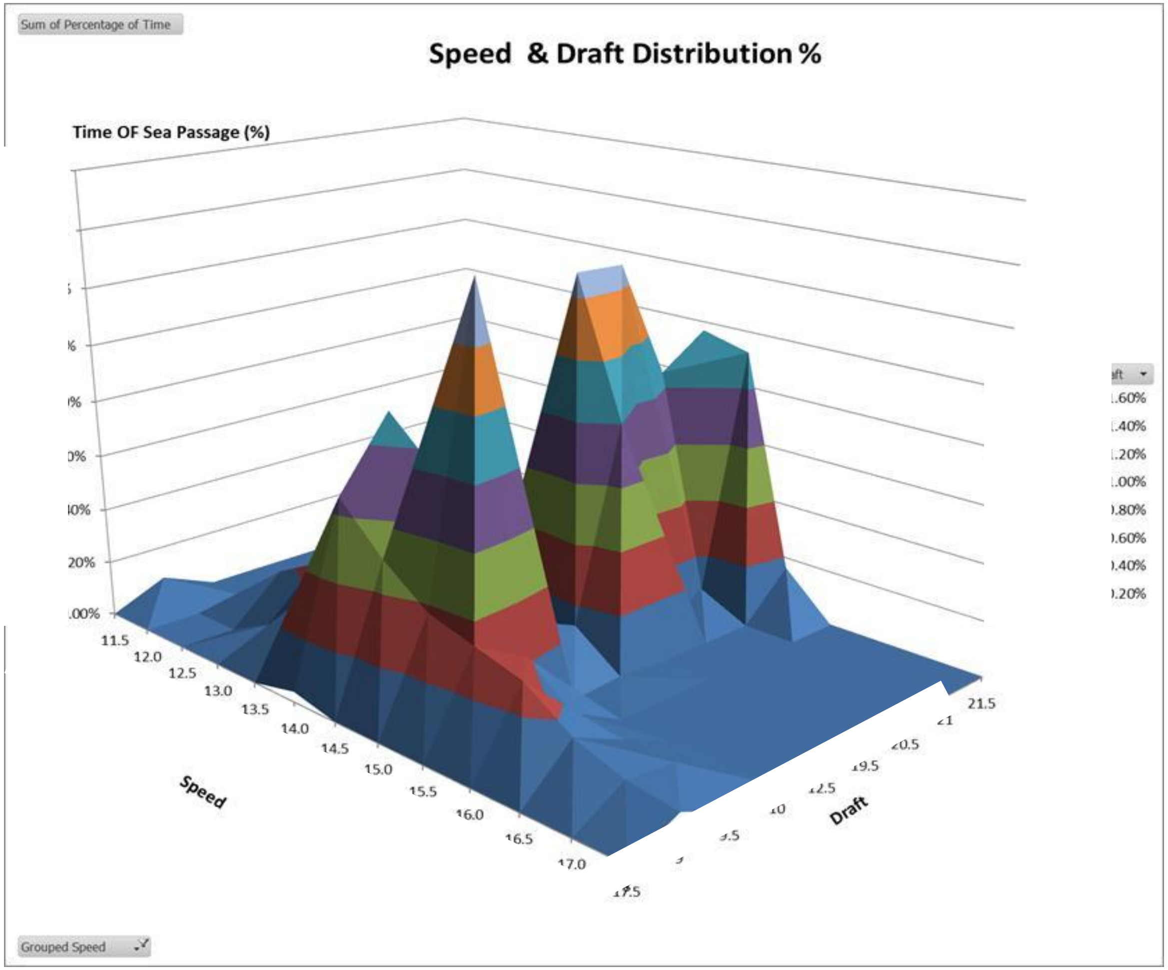


Operational Profile: Examples Laden vs. Ballast



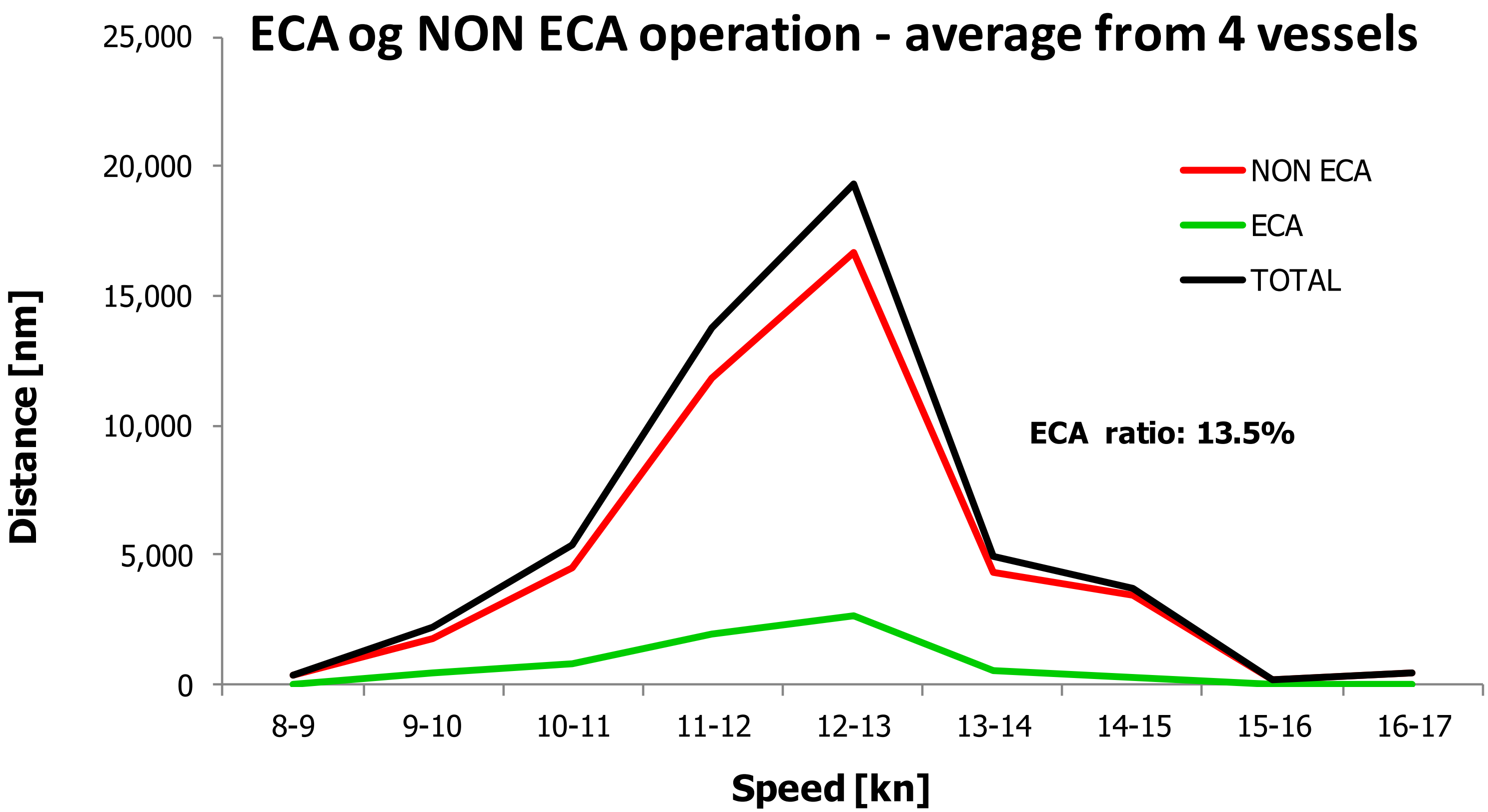
Example: Operational Profile

- Joint distribution of draft and speed



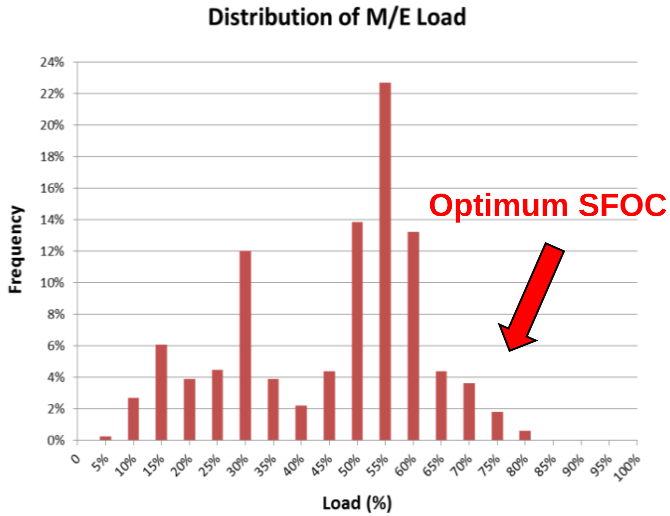
Example: Tanker Operational Profile in ECA

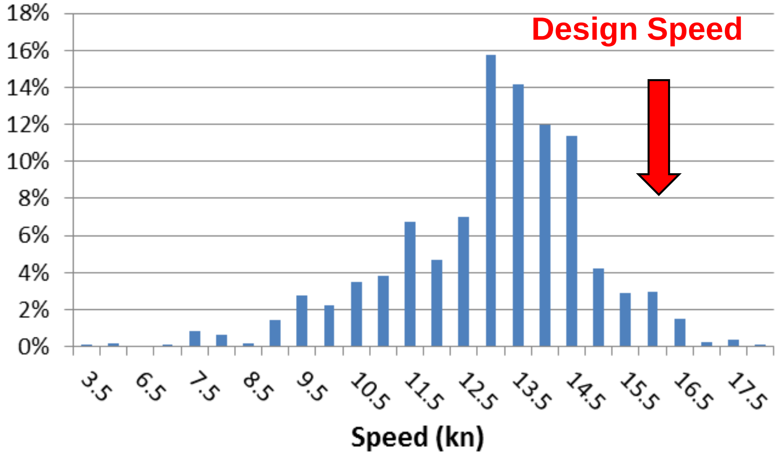
Average ECA operation: 13.5%
Maximum 17% ECA operation for one vessel.

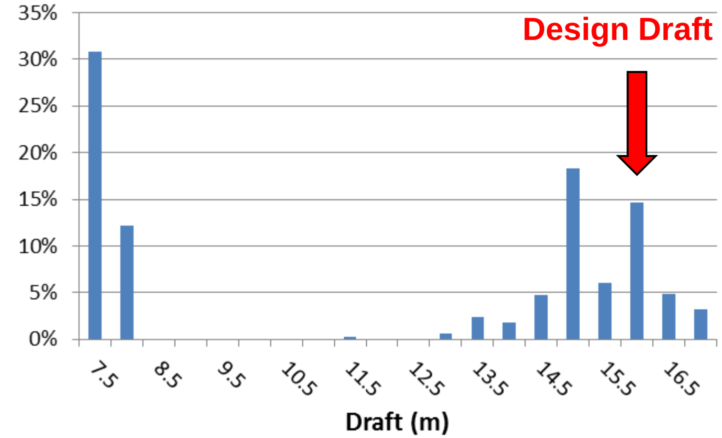


Operational Profile vs. Design Conditions

- Operational Profile
  - Distribution of drafts, speeds and M.E. load
  - Indication of original design conditions

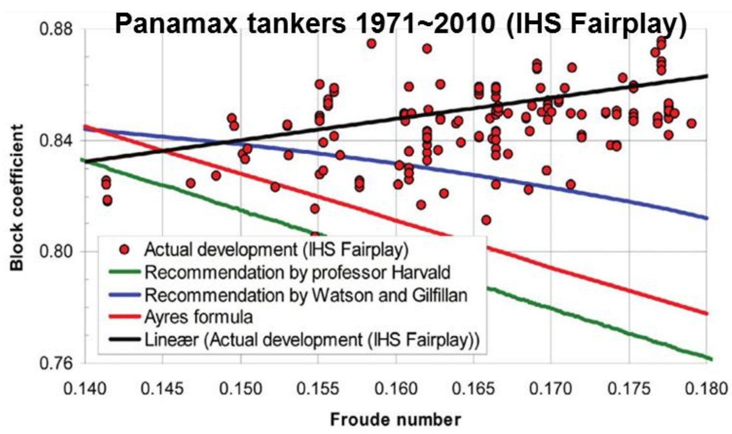




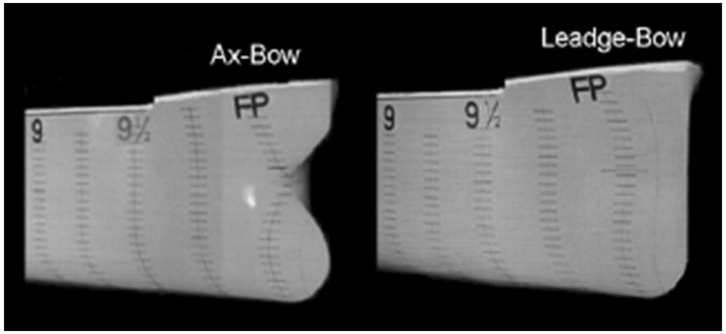


Reducing Hull Resistance in Design

- Principal dimensions: design trends not in accordance with good naval architectural principles – room for improvement
  - E.g.: C_B should be in reverse proportion to Fn; but not so in practice

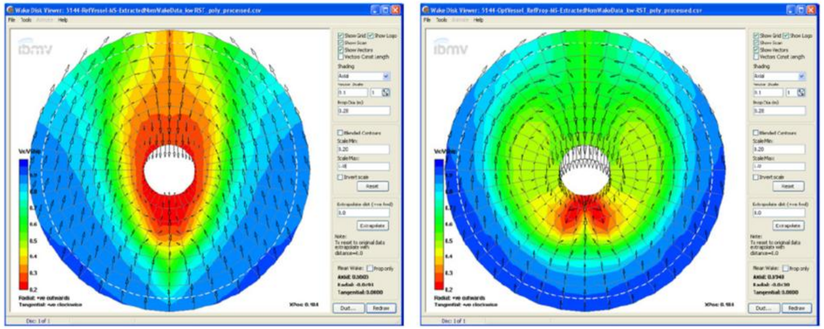


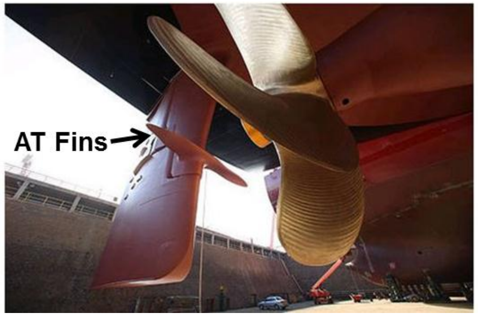
- Bulbous bow: reduce wave making resistance
  - Bulb normally designed for calm water, loaded draft, single speed
  - Should be designed for relevant range of operating conditions



Improving Propulsion Efficiency

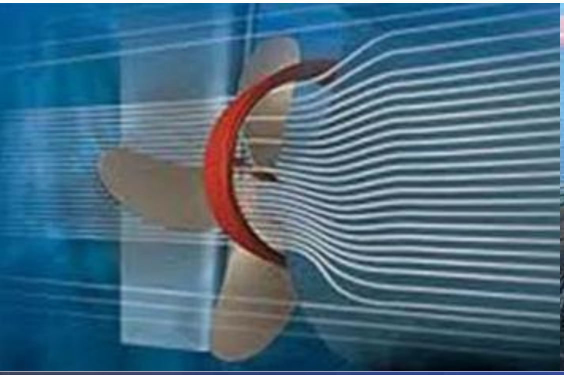
- Improve the wake field
  - Provide uniform wake field to the propeller: refine hull shape
- Recover energy or reduce vortices downstream
- Consider interaction between propeller and rudder
- Use high efficiency propellers
  - Contracted Loaded Tip (CLT) propellers, Kappel propellers, New Profile Technology (NPT) propellers

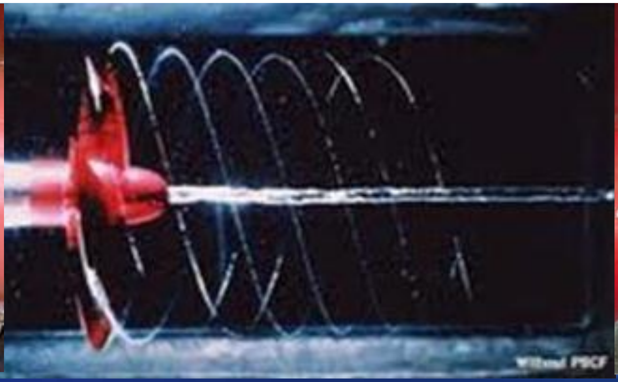




Energy-saving Devices

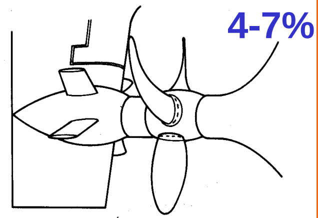
- Selecting energy-saving device
- Determining the effectiveness of devices for range of drafts and speeds in calm water (note: what happens in seaway conditions?)
- Tailoring an energy-saving device to fit a specific ship
  - For example, how to optimize propeller/hull/rudder/ES device interaction?
- Verify sufficient structural strength of the devices, no excessive vibration






Energy-saving Concepts

4-7%



Kawasaki Rudder-bulb fins

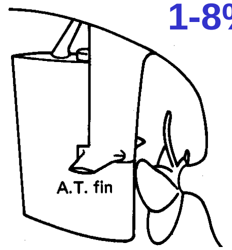
3-7%

Mitsui OSK Propeller boss cap fins

7-15%

Modern contra rotating propellers

1-8%



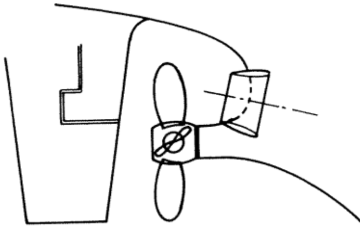
IHI Additional Thrusting Fins

based on 20th ITTC (1999)

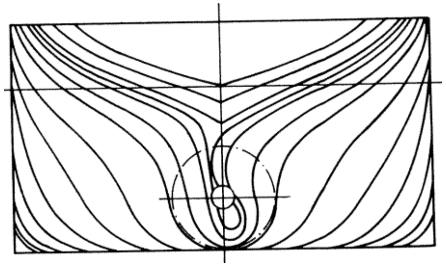
Stern flap

5-12%

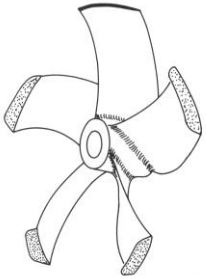
Grim wheel



Wake-equalizing duct

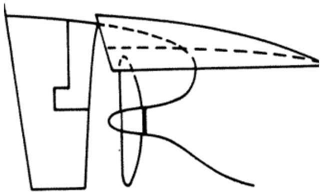


Asymmetrical stern

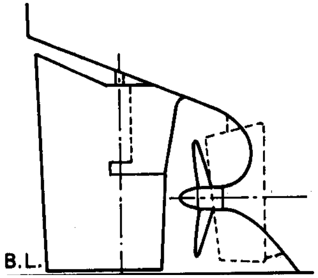


Contracted Tip propellers

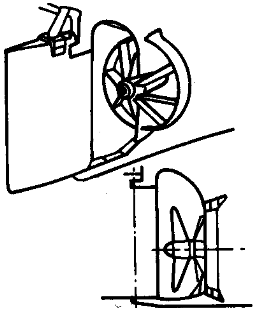
Gruthues spoilers



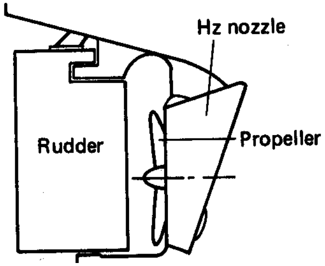
Stern tunnel



Mitsui integrated ducted propeller

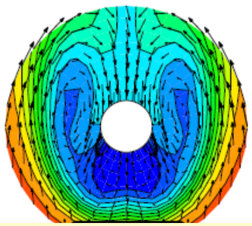


Reaction fins Takekuma

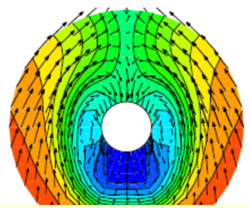


Hitachi Zosen nozzle

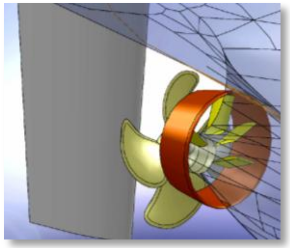
Energy-saving Devices: Possible Combinations



Original wake



Apply wake smoother



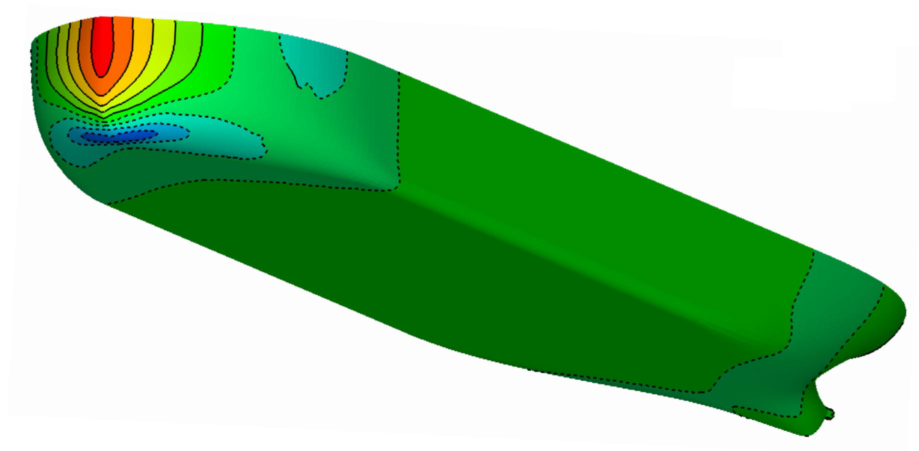
	Grothues Spoilers	Schneekluth Ducts	Stern Tunnels	Pre-swirl Devices	Pre-swirl Fins and Stators	Mitsui Integrated Ducted Propeller	Hitachi Zosen Nozzle	Sumitomo Integrated Lammeren Duct	Becker Mewis Duct	Post-swirl Devices	Rudder Thruster Fins	Post-swirl Stators	Assymmetric Rudders	Rudder (Costa) Bulb	Propeller Boss Cap Fit (PBCF)	Divergent Propeller Caps	Grim Vane Whels	High-efficiency Propellers	Large Diamter/Low RPM	Controllable Pitch Propellers (CPP)	Ducted Propellers	Propellers with End Plates	Kappel Propellers	Contra-rotating Propellers	Podded and Azimuthing Propulsion	Skin Friction Reduction	Air Cavity Systems	Micro Bubbles	Renewable Energy	Towing Kites	Flettner Rotors	Windmills	Turbosail
Wake-equalizing, Flow Separation Alleviating Devices																																	
Grothues Spoilers											C	C	C	C	C	C	C		C	PC		C	C	C			C	C		C	C	C	C
Schneekluth Ducts											C	C	C	C	C	C	C		C	PC		C	C	C			C	C		C	C	C	C
Stern Tunnels					C	PC	PC	PC	PC		C	C	C	C	C	C	C		C	C		C	C	C			C	C		C	C	C	C
Pre-swirl Devices																																	
Pre-swirl Fins and Stators											C	C	C	C	C	C			C	PC	C	C	C				C	C		C	C	C	C
Mitsui Integrated Ducted Propeller											C	C	C	C	C	C	C		C	PC		PC	PC				C	C		C	C	C	C
Hitachi Zosen Nozzle											C	C	C	C	C	C	C		C	PC		C	C				C	C		C	C	C	C
Sumitomo Integrated Lammeren Duct											C	C	C	C	C	C	C		C	PC		PC	PC				C	C		C	C	C	C
Becker Mewis Duct											C	C	C	C	C	C	C		C	PC		PC	PC				C	C		C	C	C	C
Post-swirl Devices																																	
Rudder Thruster Fins														C	C	C			C	PC	PC	C	C				C	C		C	C	C	C
Post-swirl Stators														C	C	C			C	PC	C	C	C				C	C		C	C	C	C
Assymmetric Rudders														C	C	C			C	PC	C	C	C				C	C		C	C	C	C
Rudder (Costa) Bulb																C	C		C	C	C	C	C	PC			C	C		C	C	C	C
Propeller Boss Cap Fit (PBCF)																			C	C	C	C	C				C	C		C	C	C	C
Divergent Propeller Caps																			C	C	C	C	C	PC			C	C		C	C	C	C
Grim Vane Whels																			C			PC	PC		PC		C	C		C	C	C	C
High-efficiency Propellers																																	
Large Diamter/Low RPM																				C		PC	PC	C			C	C		C	C	C	C
Controllable Pitch Propellers (CPP)																					C	C	C				C	C		C	C	C	C
Ducted Propellers																						PC	PC	C	C		C	C		C	C	C	C
Propellers with End Plates																									C		C	C		C	C	C	C
Kappel Propellers																									C		C	C		C	C	C	C
Contra-rotating Propellers																									C		C	C		C	C	C	C
Podded and Azimuthing Propulsion																											C	C		C	C	C	C
Skin Friction Reduction																																	
Air Cavity Systems																														C	C	C	C
Micro Bubbles																														C	C	C	C

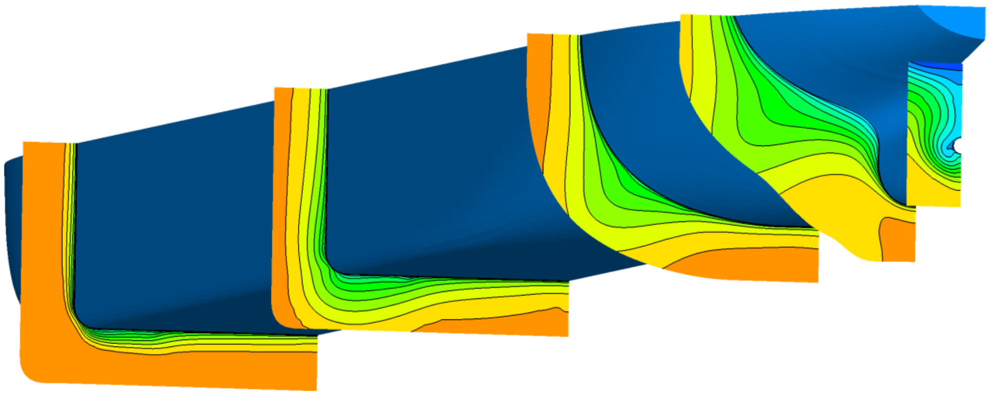
Device Compatibility

- **C** Theoretically fully compatible
- **PC** Partially compatible and overall efficiency not fully additive

Hull Form Optimization: CFD

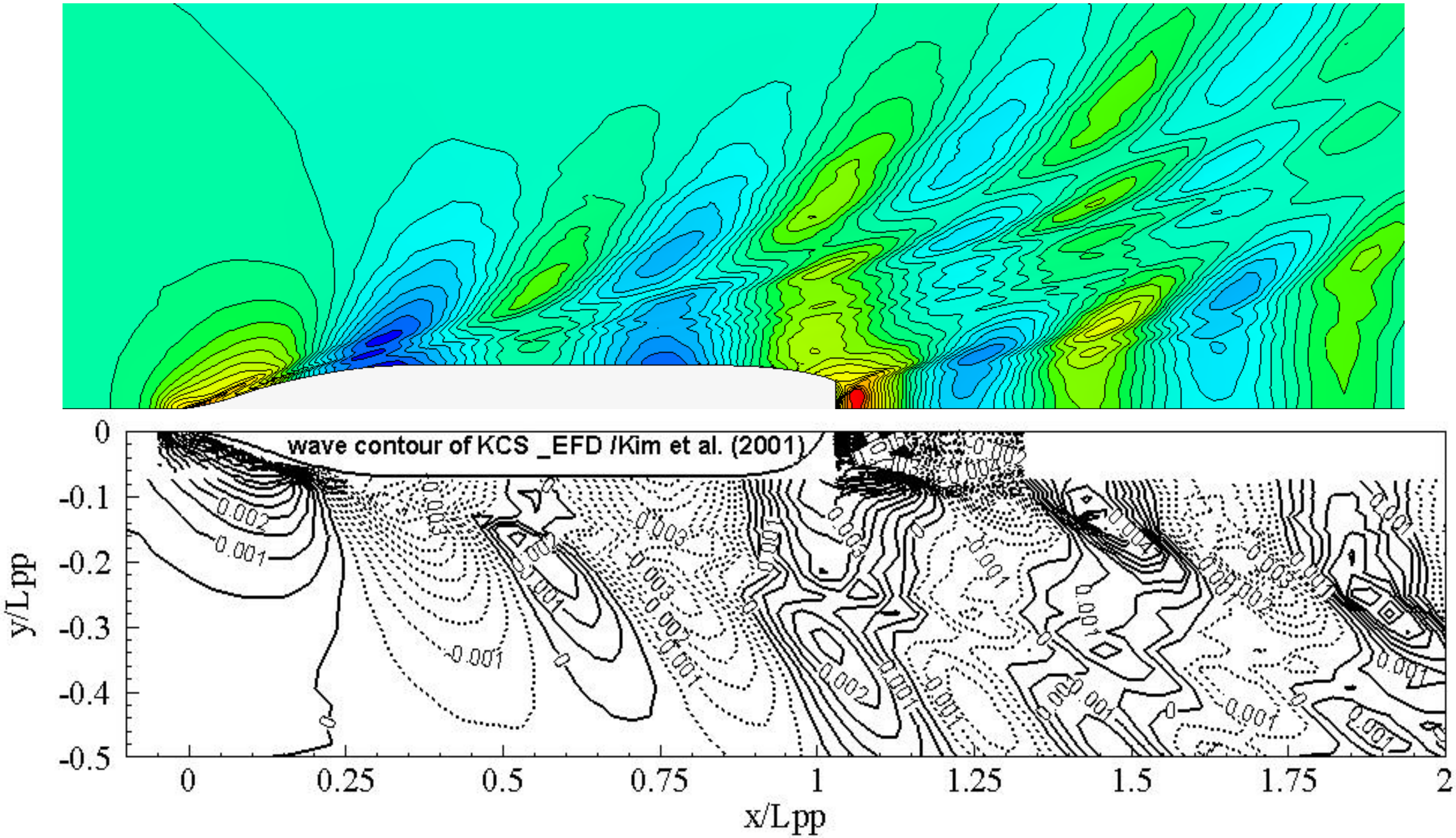
- Initial hull form design
  - Based on a parent ship and optimum dimensions, modify the hull (shape of sectional area curve, Cp, entrance, run, LCB, fairness of hull)
- Fore-body optimization
  - Bulbous bow and underwater fore-body part are the targets; can use potential flow based approach to minimize the wave resistance or CFD-RANS



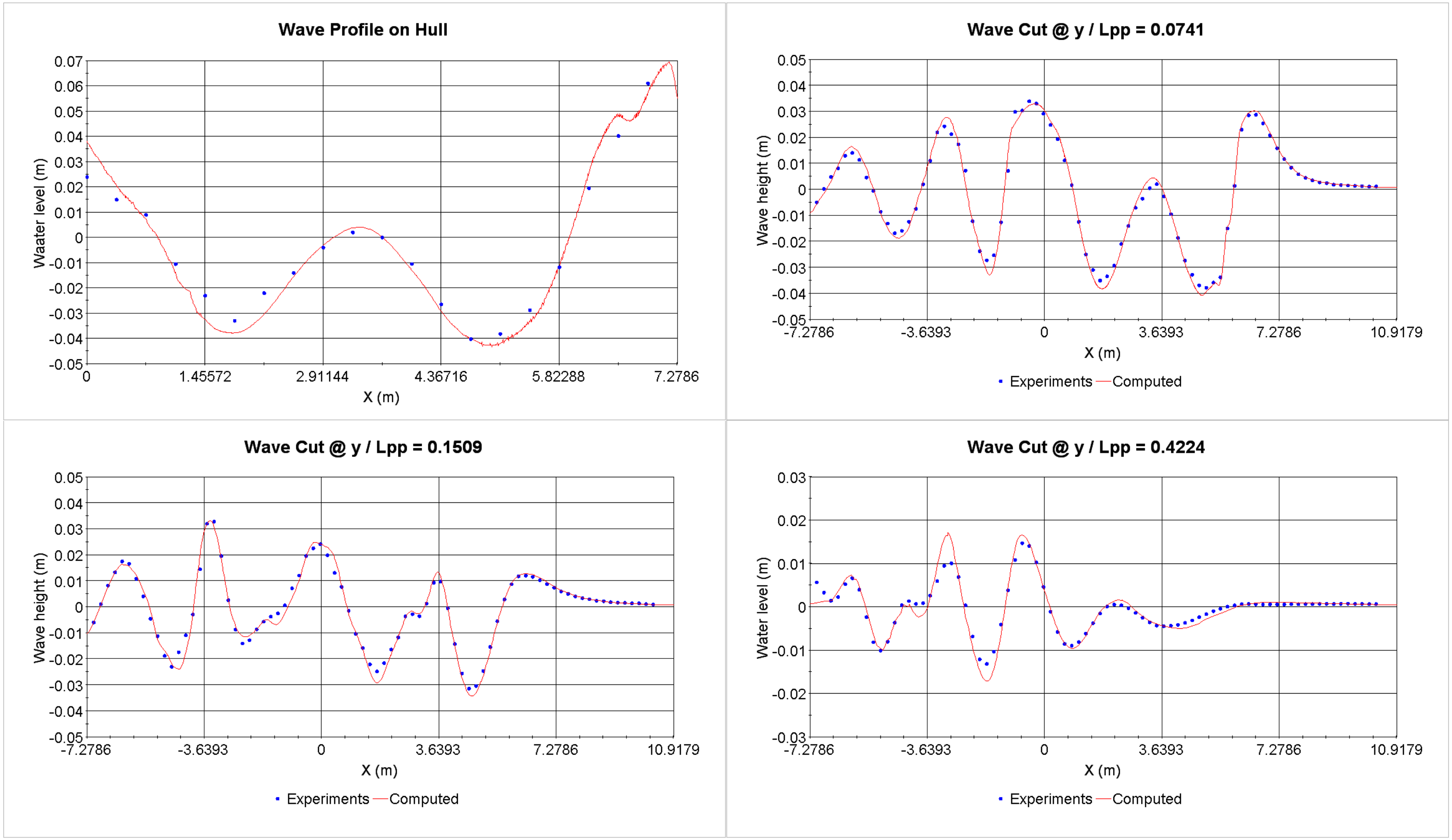


- Aft-body optimization
  - Use CFD-RANS based approach to minimize the total resistance (mainly viscous pressure and friction resistances) and improve the wake quality as much as possible
  - Propeller selection, minimize average power
- Model test verification

Resistance & Propulsion: CFD Validation

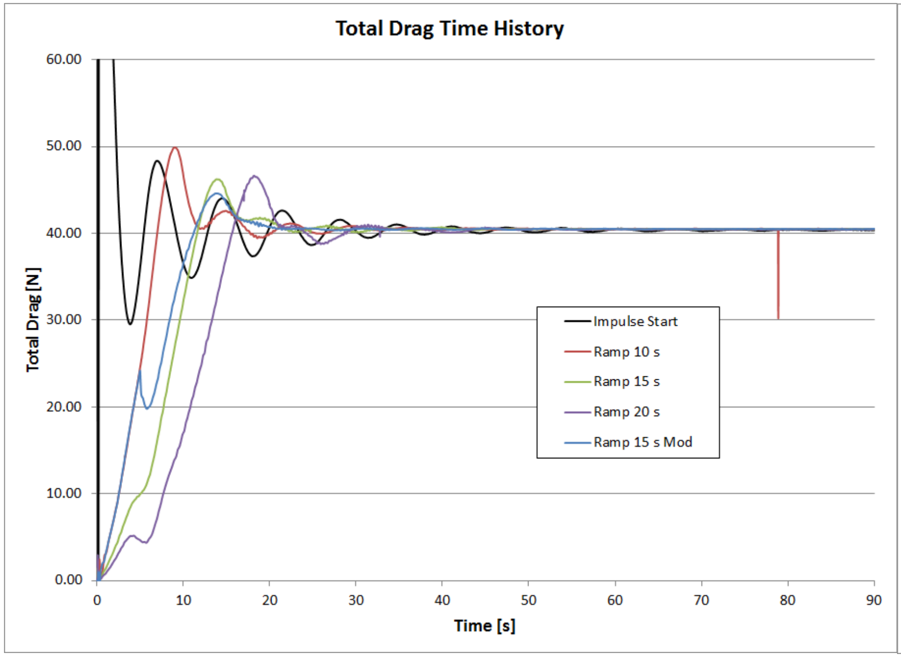


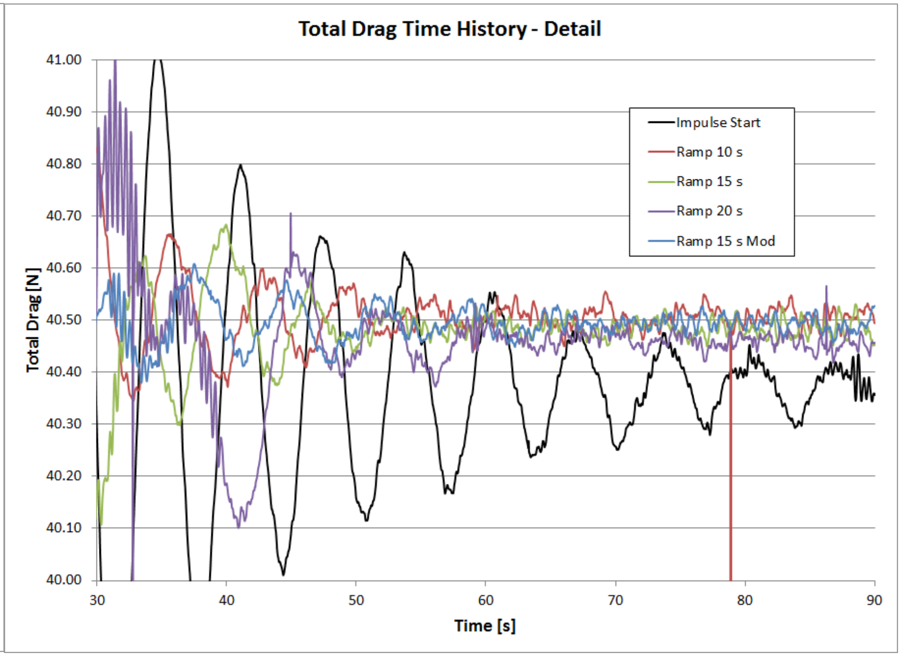
CFD: Resistance & Propulsion (Validation)



CFD: Resistance & Propulsion (Practicality)

- An un-propelled 2,000,000 point grid requires about 8 hours running on 8 cores (propelled requires 50% to100% longer)
- Convergence can be improved by carefully managing transients (BCs and ramped ICs)
- Added bonus: improved accuracy -- average error reduced to 0.8% vs. -1.07% with impulse start



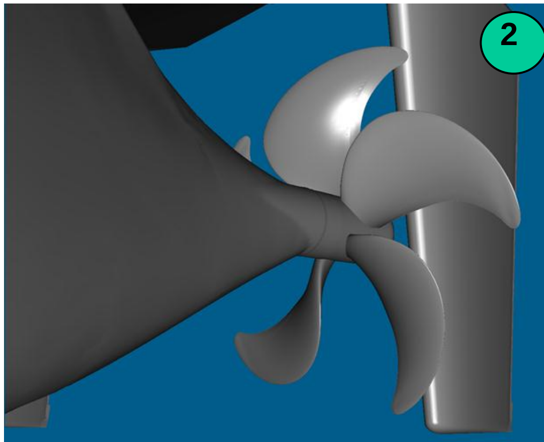


CFD: Propeller Optimization in Wake Field

1

Required inputs:
- parameterized pitch, chord, rake, skew vs. radius,
- blade section shape versus radius,
- Hull shape NURBS
- Rudder shape NURBS

2



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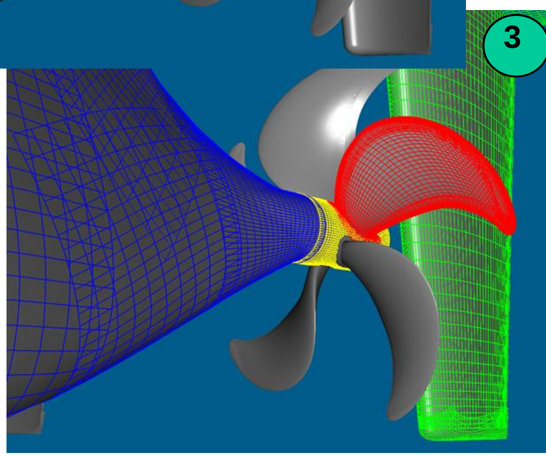

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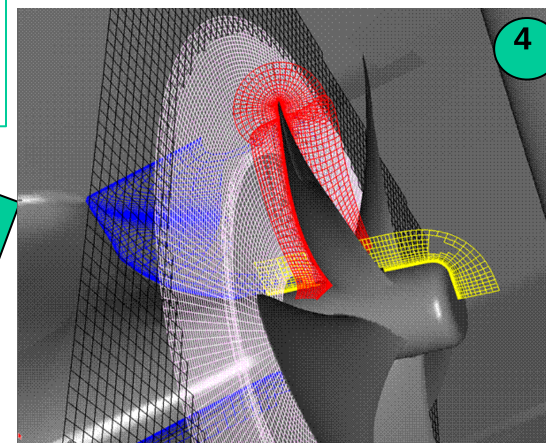

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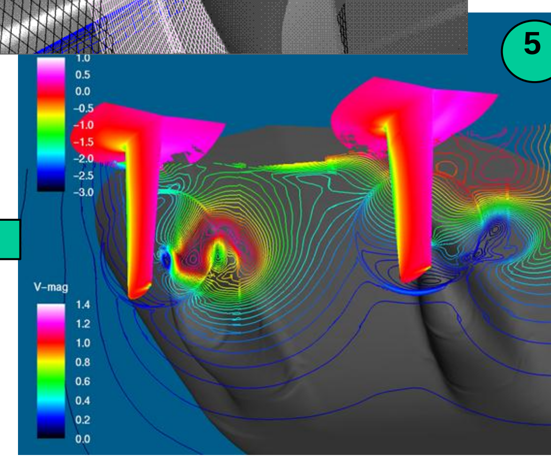

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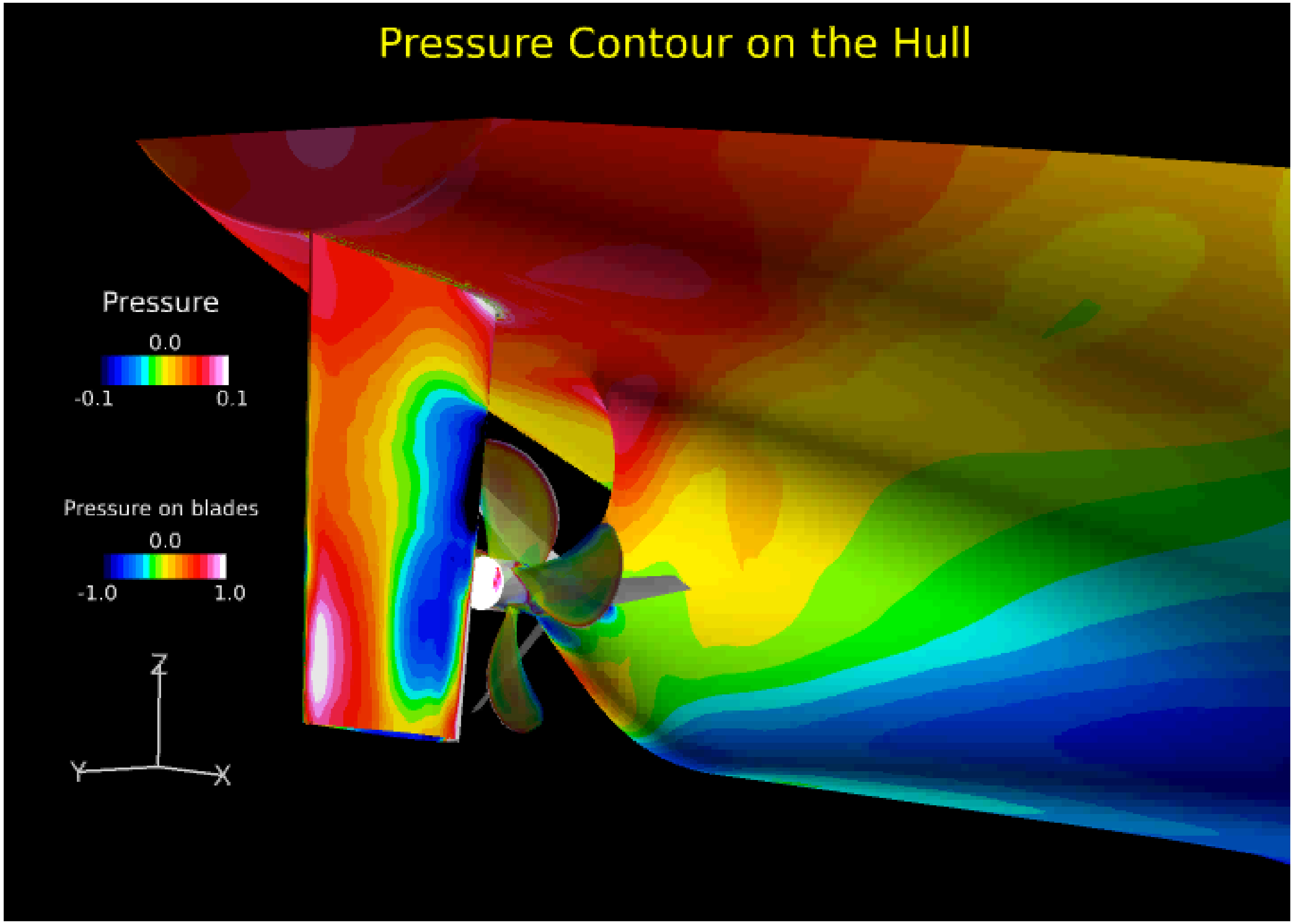
Outputs:
- SHP
- Minimum blade pressure vs shaft angle.
- Minimum field pressure vs shaft angle.

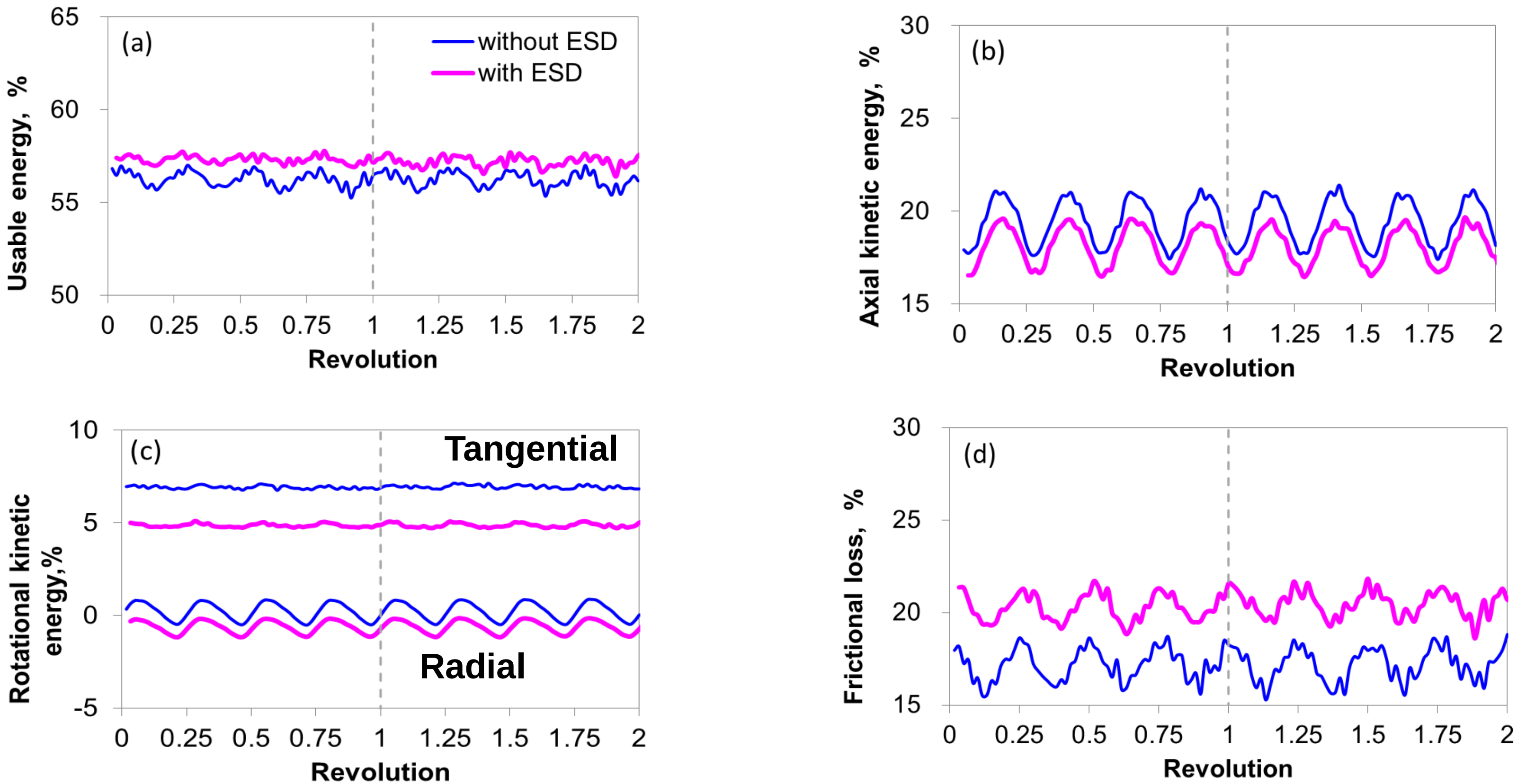
Propeller/Hull/Rudder/ESD Interaction Case



CFD: Verify ESD Performance
Energy Component Breakdown

					[%]
	Usable	Axial KE	Rotational KE		Frictional
			normal	tangential	
without ESD	56.24	19.41	0.23	6.94	17.18
with ESD	57.32	18.09	-0.62	4.87	20.39

without ESD
with ESD

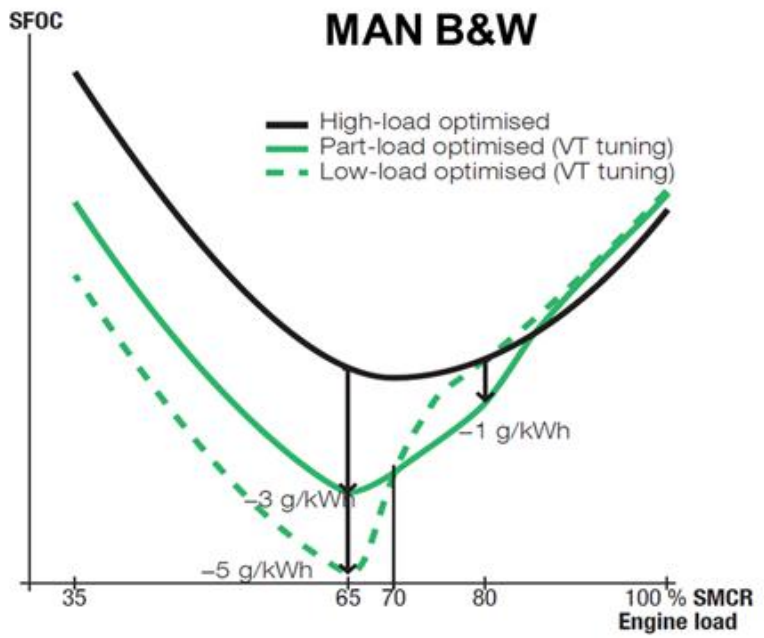


Machinery: Design for Energy Efficient Operation

- Minimize fuel consumption across a ship's operating profile
- Hull powering requirements
  - Speed and loading conditions
- Propulsor efficiency
- Alternative propulsion plant tradeoffs
- Main engine technology options
- Electrical plant requirements
  - Loading conditions and equipment
- Generator set sizing

Improve Engine Efficiency

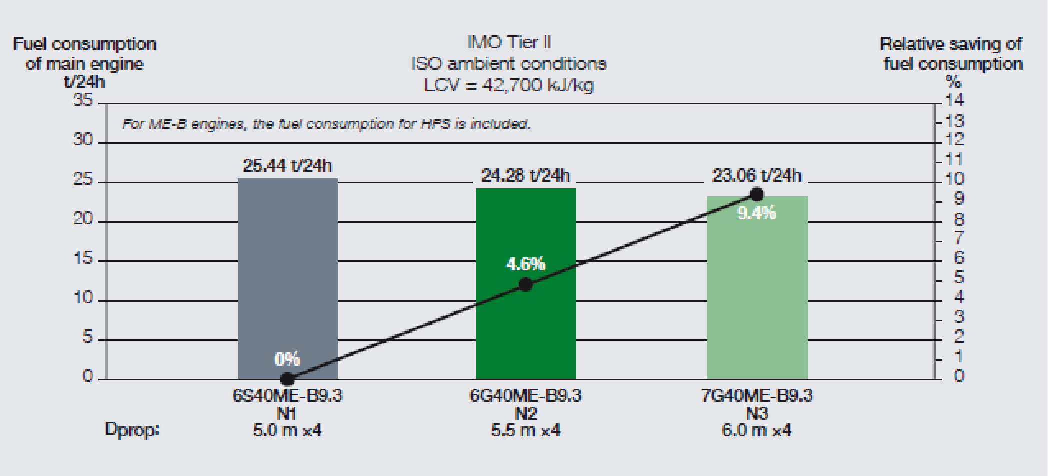
- Increase engine efficiency
  - Technology: electronic control; turbocharger technology; longer stroke; spread fuel efficiency across wider operating load range
- Increase number of cylinders and derate
  - Lower fuel consumption
  - Higher initial cost; payback period
- Energy efficiency enhancement
  - Exhaust gas bypass (EGB)
  - Variable turbine area or turbine geometry
  - Sequential turbo-charging
  - Turbocharger cut-out
  - Two-stage turbo-charging

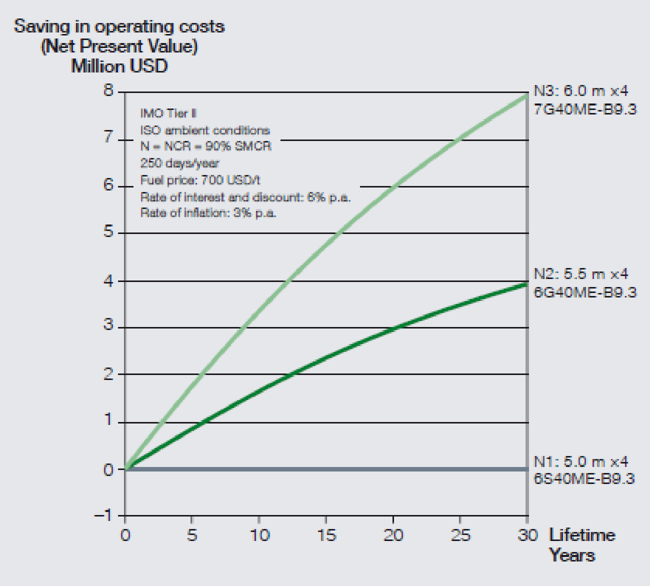


Part-load optimization to reduce SFOC at loads below 85% MCR or low-load optimization to reduce SFOC at loads below 70% MCR, at the expense of higher SFOC in the high-load range

Main Engine Selection

- Large diameter propeller and low rpm lead to savings
- Operating costs in terms of NPV



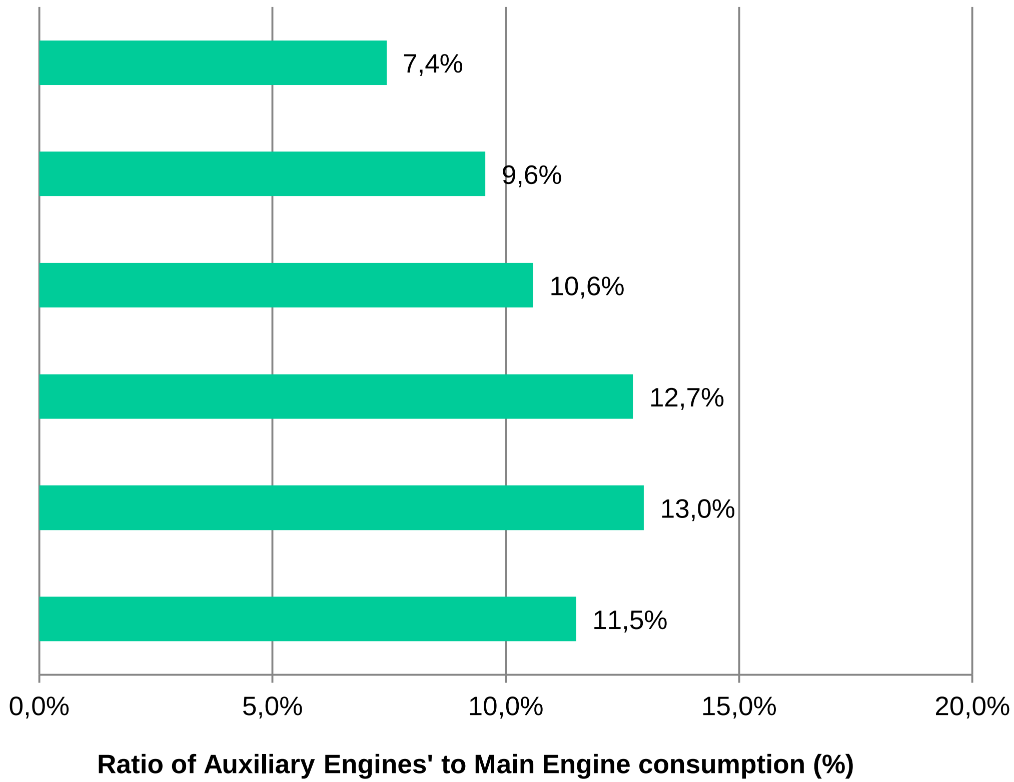


Machinery System Components Room for Energy Efficiency Improvements

Element	Features
Main engine optimization	Apply autotuning, derating, turbocharging technologies, e.g. Variable Geometry Turbine, T/C bypass, 2-stage T/C, T/C cutout
Machinery optimization: WHR	Waste heat recovery system for main engine based on operational profile and technical specifications.
Machinery optimization: PTI/PTO	Application of power take-in and power take-out technologies, also in conjunction with design for lower speed and ability to run vessel at higher catch-up speed using PTI and shaft generator.
Pump system optimization	Fuel efficiency improvement due to application of variable frequency drives (VFDs) for demand/load dependent control of e.g. main engine cooling pumps. High efficiency pumps.
Ventilation and HVAC optimization	Fuel efficiency improvements due to VFD fan control and duct design. HVAC system analysis.
Machinery optimization: ORC	Application of Organic Rankine Cycle technology for low level waste heat recovery from main engine cooling water.
Economizers	Improve efficiency by installing an economizer (boiler) to recover waste heat from auxiliary engine.

Operational Profile: A/E Fuel Consumption

- Example: series of tankers
- Aux. engine fuel consumption as a % of M.E. fuel consumption



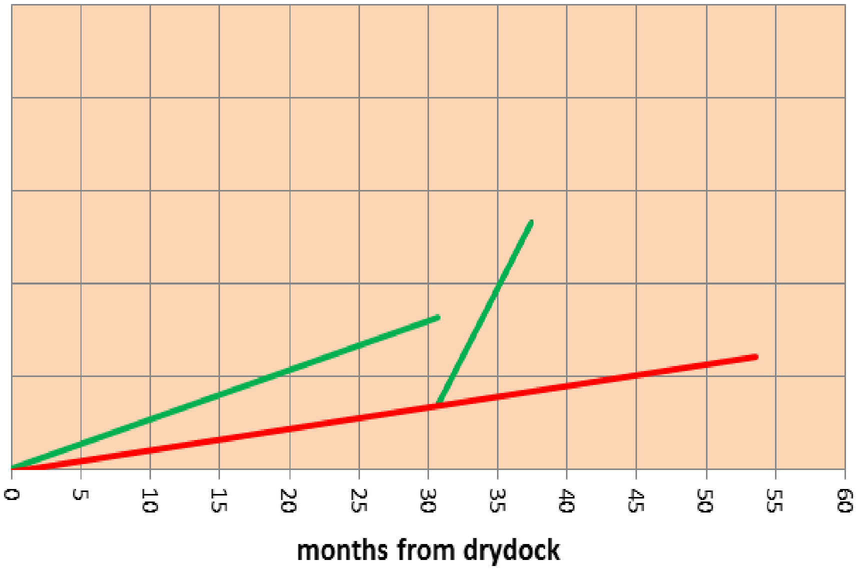
Operational Performance of Existing Fleet

- Technical
  - Hull and propeller efficiency
  - M.E. efficiency
  - Electrical consumption
  - Electrical production
  - On the average merchant fleet of today – huge potential
- Operational
  - Voyage optimization
    - Planning
    - Conditions
  - Fleet utilization (EEOI)
    - Cargo carrried
    - Speed (slow steaming)
  - Fleet composition; pools, operators

Requires a structured process to improve
Monitoring – analysis – benchmarking - decision support

Fuel-savings: Hull & Propeller Maintenance

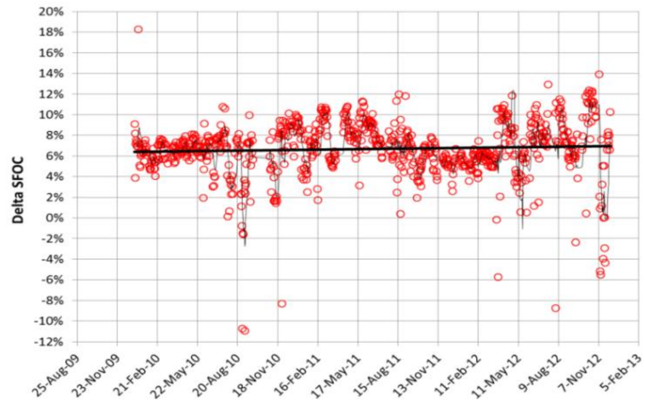
- Drydocking
  - Full blast – spot blast
  - Paint systems, new technologies not always performing?
  - Evaluation of treatment
- In Operation
  - Trending of performance
  - Hull cleaning – intervals, type of cleaning on different paint types
  - Propeller polish
  - Evaluation of treatment

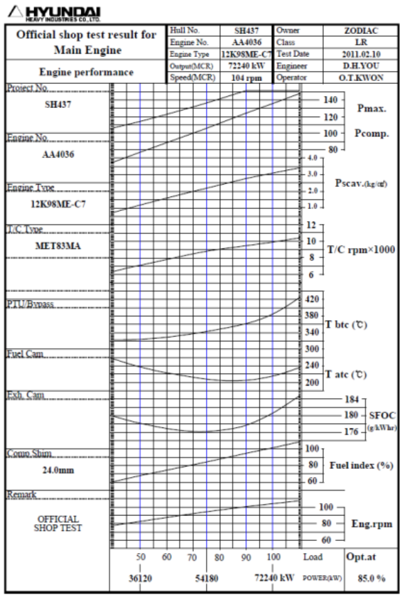


- Careful monitoring and analysis are a prerequisite

Fuel-savings: Main Engine Efficiency

- Engine must be maintained for efficiency and to reduce maintenance costs
- Engine efficiency
  - Measure fuel and power
- Trending of SFOC
- Engine test
  - High Pmax – High SFOC
  - Engine balance
  - ISO correction for ambient conditions
- Slow steaming – low load operation
- No easy catch
  - Continuous monitoring and follow-up required



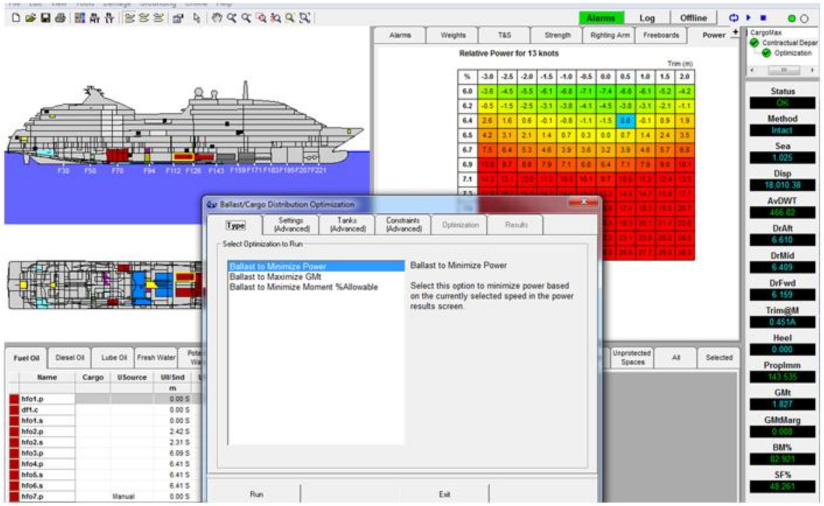


Fuel-savings: Base Load – Production

- Minimize energy consumption
  - Turn off unnecessary lights, A/C, etc.
  - Change to EE bulbs
  - Proper maintenance of consumers
  - And a lot more
- Optimize energy production (energy management)
  - "Classic" – verify that auxiliaries are run at optimum load, i.e. avoid low load operation on several engines
  - SFOC on auxiliary engines
  - PTO, WHR options, are the crews using it optimally?
- Measuring fuel consumption for auxiliaries and energy production not always prioritized
- Base load monitoring and feedback required

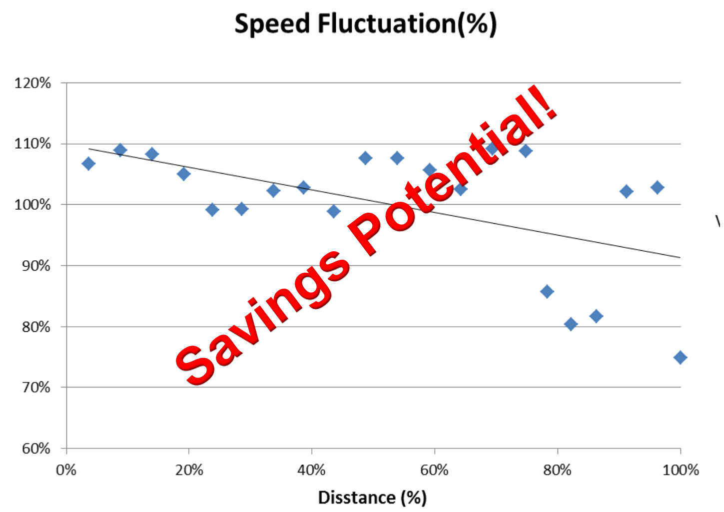
Fuel-savings: Trim Optimization

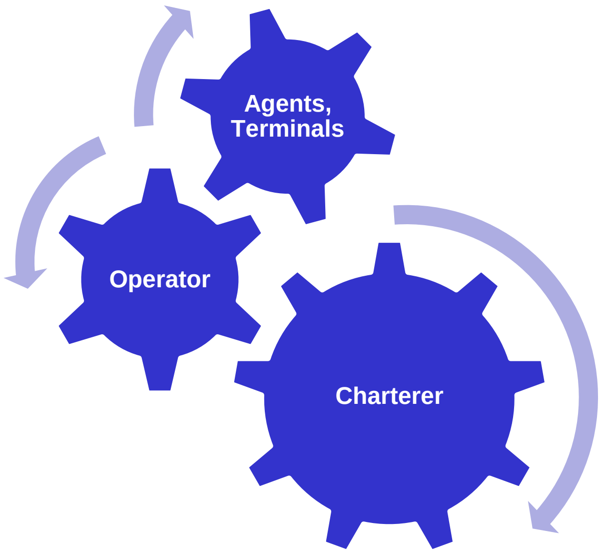
- Tables of optimum trim as function of speed and displacement
  - Model tests
  - CFD calculations
  - Self-learning algorithms from full scale
- Verification? Absolute numbers are important.
- Loading of container vessels done by stowage, need to understand, link to loading computer
- Monitoring and follow-up required, optimum trim not only parameter



Vessel Performance: Voyage Planning

- Considerations:
  - Appropriate charter party clauses
  - Communication of voyage conditions at an early stage, fast communication of ETA changes
  - Speed profile optimization
  - Just in time arrival

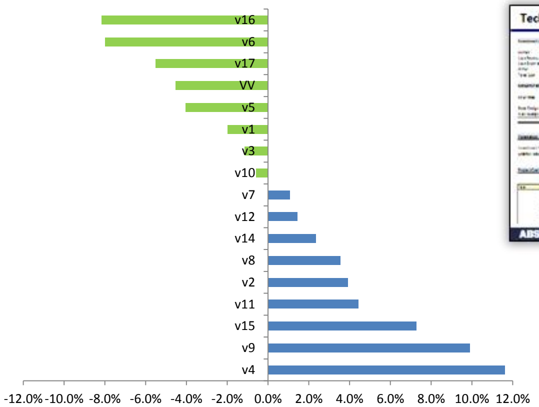


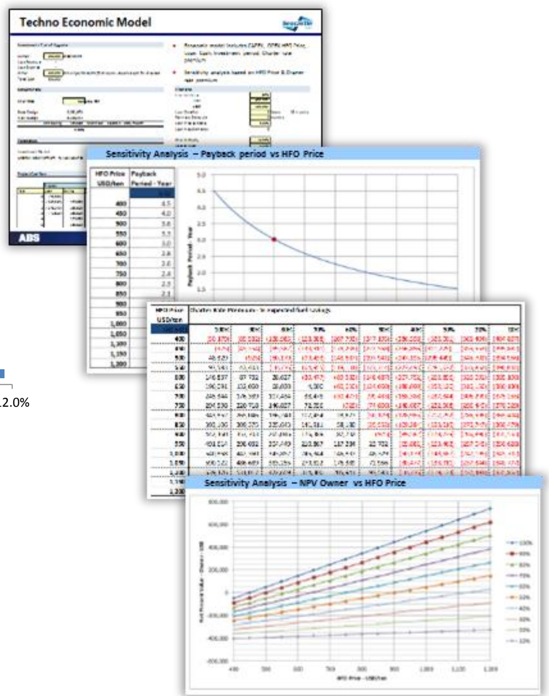


ABS Services: Energy Efficiency

- Services
  - Design indexing and benchmarking
  - Hull and propeller optimization
  - ESD evaluation
  - Techno-economic modeling
  - Specification review
  - Advisory of energy regulations – best management practices
  - EEDI verification

- **Function:** services used to assess the current energy efficiency of new or existing vessels and to determine both the technical and financial impact of investing in upgrades.





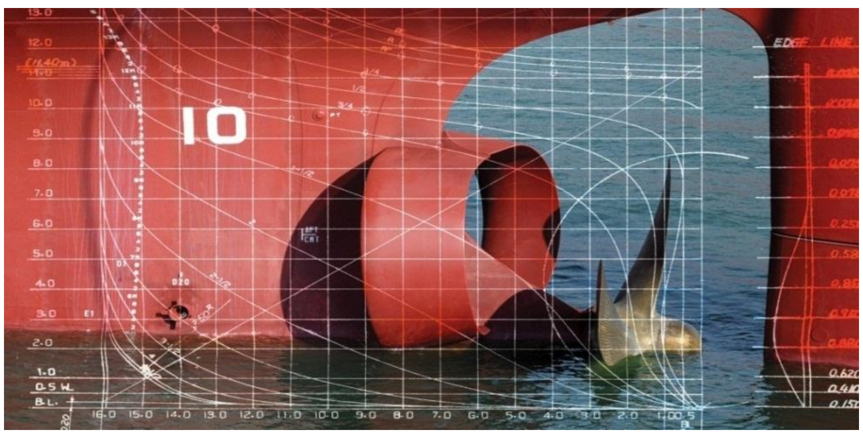
Design Benchmarking

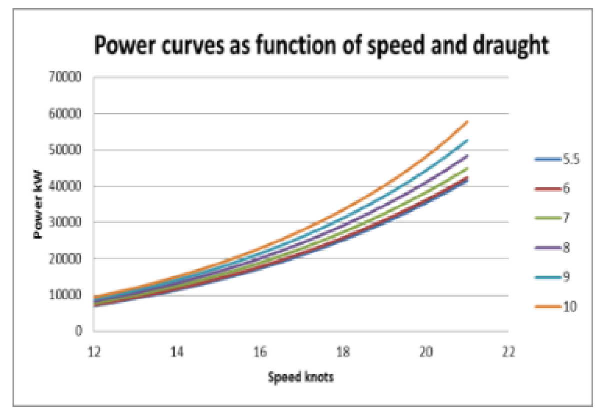
- How energy efficient is a ship's design…
  - What is/are suitable metric(s) to benchmark a given design?
  - EEDI?
    - Will a low EEDI guarantee an energy efficient ship for the complete range of operational conditions? And will a ship with low EEDI be more energy efficient during operation than a ship with high EEDI?
  - How to achieve a comparison between different vessels on an equal basis?
  - How to take into account the operational profile?

OEP Services: Vessel Performance

- Services
  - Performance monitoring
  - Performance analysis
  - Performance optimization
  - Energy audits
  - SEEMP consultation

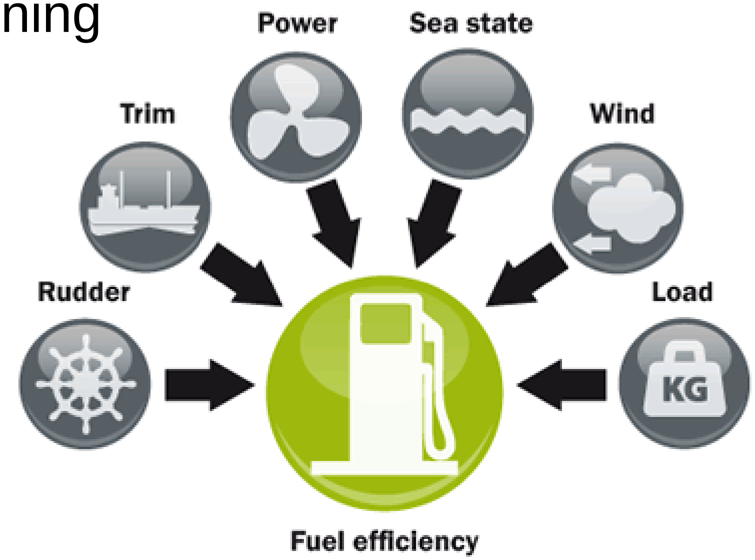
- **Function:** services to evaluate the performance of a vessel, benchmark its performance against its original design and similar vessels, and to offer solutions based on fuel saving strategies, to bring about the optimization of performance





Summary

- There is significant potential to improve the energy efficiency of new and existing vessels
- Fuel efficient design requires a holistic approach: integrated hull, propeller and machinery systems optimized for operational profile
- Fuel efficient vessel operations require:
  - Monitoring system and a framework
  - The human factor – communication, training
- ABS services:
  - Operational and Environmental Performance
  - Data management – Nautical Systems
  - Training – ABS Academy courses



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